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U. S. Department of Agriculture
Bureau of Agricultural Engineering
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PROGRESS REPORT ON DRAFT OF PLOWS USED FOR CORN BORER CONTROL

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April, 1932

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INTRODUCTION

There is widespread interest in the development of more efficient plows for corn borer control and other purposes. While quality of work is of first importance, draft influences the cost of operation, and must be given serious consideration.

Kinsman in Department Bulletin No. 1348 "An appraisal of power used on farms in the United States" estimates the power per annum for plowing and listing at 2,500,000,000 horsepower hours. A saving of even a very small percentage of this power would make a sizable reduction in the annual cost of these operations. The findings from tests presented herewith, show that in some cases packing of moderately moist clay loam soil by implements was responsible for as much as 20% of the total draft of the plows tested, while variations in weight and wheel arrangement accounted for changes up to 12% and differences in type of plow bottoms for changes of 10% in draft requirements. Therefore, it seems possible to achieve sizable savings through improvements in design and operation. Of still greater importance are proper treatment of soil, and determination of the right time for plowing, which may effect savings in draft of 30% or more.

Need of a measure of soil resistance.

Experience has shown that local peculiarities and variations in the soil are large, and changes occur so quickly as to introduce into the test work unknown factors which distort the data. For this reason a body of test data taken under reasonably uniform conditions is much more valuable for comparative purposes than an equal amount of data gathered in more than

one series of tests, unless special precautions have been taken to relate the work by means of indices of soil characteristics or by use of one or more similar plows in each series of tests. A ready means of measuring soil resistance directly is needed to harmonize data obtained in any comprehensive series of tests as well as to make possible valid comparisons between data collected at different times or places.

At present, the best mechanical means of comparing results seems to be by use of a check plow run at frequent intervals during the test series. This plow should be kept in uniform adjustment and operated after every second one of the plows tested, or possibly after every one, depending on the time elapsed between tests in a series, and on uniformity of field conditions. In this way a comparable measure of soil resistance may be obtained. Keen (7) makes a similar recommendation.1/ Tests made by the various experiment stations would be much more valuable if all would follow a uniform practice, agreeing on some plow as a check and making its use a part of all testing programs. The principle applies to tests for either draft or coverage.

1/ Tests at the Rothamsted Station show that the soil resistance over a field that appears to be uniform may vary considerably. Isodyne maps (that is, maps with contours of equal draft) were constructed to show the variations in soil resistance for several fields. Two methods are suggested for use in correcting for soil variations: (a) use one implement in each plot as a check; (b) construct isodyne maps for the test fields. It was found that the isodyne in general are unaffected from season to season (correlation factor 0.897). For general use the first of these two methods is preferred, since comparative draft tests may be made in one season.

The Committee on Soil Dynamics of the American Society of Agricultural Engineers in its 1931 report recommended that in addition to the use of a check plow, the following soil properties be measured in future draft tests:

A. The plasticity of the soil, as estimated by the Atterberg plasticity tests. 2/

B. The moisture content.

C. The volume-weight (apparent specific gravity).

Test methods should consider separate factors.

In a detailed study of the draft of plows, the effect of each variable factor should be studied separately, so far as possible. In addition to soil properties variable factors may include among others, proportion of soil area packed by the tractor to total area plowed; wheel equipment and weight of plow and tractor; type of plow bottom equipment; type of plow attachments; and adjustments of plow and attachments.

Value of correlation methods.

In the absence of adequate data regarding separate factors, analysis of available data by correlation methods shows the individual trends of the factors involved, gives a view of progress, and lays the groundwork for a more careful study of the important factors in future experiments. The system of plow bottom measurements described by Ashby (2) provides a basis for a correlation study of the effect of shape on both draft and coverage.

2/ The Atterberg plasticity number of a soil is the difference expressed in per cent between the least amount of moisture necessary to allow a small mass to flow slightly when jarred and the least amount of moisture required to roll it into a wire 1/8 inch in diameter without crumbling. See reference (8), p. 23.

NATURE AND SCOPE OF DRAFT INVESTIGATIONS

The chief purpose of the draft tests described herein is to outline methods for more conclusive studies in the future. The relative importance of the factors affecting draft was not well understood when the first series of tests was begun and insufficient attention was paid to soil characteristics in the fields where the tests were made. Methods were improved progressively as the work developed the need for additional information. Though the data available have been analyzed carefully, it should be understood that the findings represent probable and not proved relationships.

Draft records of 25 plows were obtained in the fall of 1928, in connection with the coverage experiments described in (1). An oil-cylinder type of recording dynamometer and medium-weight wheel tractors with spade lugs were used and records were made at both 6-inch and 8-inch depths. Each plow at each round crossed plots which had been single disked, double disked, and rolled with cultipacker, as well as one to which no treatment had been given. The corn had been picked with a tractor-drawn mechanical corn picker. Usable draft records were secured for 22 plows at 6-inch depth and for 21 at 8-inch depth. The average distance traveled in making each record was about 2,000 feet. Ten plows were tested at 6-inch depth at two rates of travel--$2\frac{1}{2}$ and $3\frac{1}{4}$ miles per hour. In all tests the plows were equipped with standard rolling colters, jointers, and covering wires.

During June and July 1931 a group of 158 variable speed draft tests were run near Toledo, Ohio. The soil is a clay loam. The field was last plowed during the spring of 1927. No crop was put in that season or since. It was necessary to mow the weeds, then partly fill the old dead

furrows by disking before tests could be made. All preparation work on the field was done at right angles or diagonally to the direction in which the test furrows were to be run, so that all tests crossed the wheel tracks and were uniformly packed. Records were obtained using two plow bottoms in test frames, two sources of power, and at three conditions of soil moisture, thus dividing the tests into six series as shown in Table 8. In these tests the plows were equipped with standard rolling colters. Special equipment used for the tests is shown in Figures 1 to 4.

A number of comparative tests to obtain information about the effect of plow attachments on the draft; relative draft of 1, 2, and 3 bottom plows; draft of plows of various sizes; and effects of disking, double disking, etc., on draft, were made in the spring of 1928 on sandy loam and clay loam soils using an Iowa integrating dynamometer. These tests were made in corn fields from which the stalks had been removed, leaving 8-inch stubble.

ANALYSIS OF THE 1928 TESTS

On account of local variations in soil resistance and irregularities in the surface, such as the position of the corn row with respect to the colter and jointer, there are considerable variations in data from individual tests. It is thought, however, that the average draft on the eight plots of Field No. 1 (See Table 1) is a fairly reliable index of the comparative power requirements of the plows tested when proper allowances are made for variations in soil resistance due to moisture, as discussed under "Effect of rainfall on soil resistance".

Table 1.- Summary of draft of plows for Field No.1 in pounds per square inch as influenced by treatment before plowing

Plow No.	Size of plow	Date (6-inch)	6-inch depth: Not treated	6-inch depth: Single disked	6-inch depth: Double disked	6-inch depth: Rolled	6-inch depth: Average	Date (8-inch)	8-inch depth: Not treated	8-inch depth: Single disked	8-inch depth: Double disked	8-inch depth: Rolled	8-inch depth: Average	Average of 6-inch and 8-inch
1	2-12-inch	11/1	12.1	13.2	13.2	12.2	12.7	11/1	9.5	9.6	11.3	10.4	10.2	11.4
2	2-12-inch	11/6	11.9	11.9	12.9	12.6	12.3	--	--	--	--	--	--	--
3	2-14-inch	10/26	11.7	10.1	12.0	11.6	11.3	10/27	8.8	8.0	8.9	8.2	8.5	9.9
4	2-14-inch	11/6	11.0	11.2	13.7	12.8	12.2	11/6	10.4	10.1	10.9	11.5	10.7	11.5
5	2-14-inch	11/1	9.7	10.9	13.2	10.9	11.2	11/2	8.6	10.4	11.7	11.7	10.6	10.9
6	2-14-inch	10/31	11.0	11.4	11.1	11.0	11.1	10/30	8.4	10.1	10.4	8.6	9.4	10.3
8	2-14-inch	10/30	8.0	8.0	9.3	8.8	8.5	10/30	8.6	9.7	10.9	9.4	9.7	9.1
9	2-14-inch	10/30	11.0	9.8	10.6	10.1	10.4	10/30	7.9	10.5	10.7	9.1	9.5	10.0
10	2-14-inch	11/5	13.0	11.7	11.4	13.3	12.3	11/5	10.5	10.5	--	--	11.1*	11.7
10	2-14-inch	11/7	11.9	11.3	11.2	11.9	11.6	11/7	8.3	8.1	10.0	10.2	9.1	10.3
13	2-16-inch	10/29	10.2	8.3	10.1	9.6	9.5	10/29	8.3	8.9	10.6	9.0	9.2	9.3
14	2-16-inch	10/26	12.3	10.4	10.9	10.7	11.1	10/26	9.0	9.2	8.8	8.0	8.7	9.9
15	2-16-inch	11/2	10.5	11.9	12.8	10.9	11.5	11/2	7.6	9.2	11.1	10.9	9.7	10.6
16	2-16-inch	11/6	9.2	10.5	11.5	10.9	10.5	11/6	9.8	9.6	10.5	11.3	10.3	10.4
17	2-16-inch	10/29	10.1	9.9	11.3	10.6	10.5	10/30	8.7	9.0	10.2	8.9	9.2	9.8
18	2-16-inch	10/26	10.6	9.6	9.4	9.3	9.7	10/26	7.5	6.6	7.5	6.9	7.1	8.4
19	2-16-inch	11/1	12.3	12.7	12.6	10.7	12.1	11/1	7.8	9.4	9.6	9.1	9.0	10.5
23	2-18-inch	11/5	10.6	10.8	11.5	11.0	11.0	11/5	8.8	9.5	9.0	9.7	9.3	10.1
24	2-18-inch	10/31	11.5	12.7	12.9	10.7	11.9	11/1	7.9	8.6	10.0	9.5	9.0	10.5
12	1-16-inch	11/8	12.7	12.6	12.7	13.3	12.8	11/8	10.9	11.1	12.1	12.4	11.6	12.2
20	1-18-inch	11/7	13.2	13.9	14.6	13.4	13.8	11/7	10.5	10.4	11.6	12.5	11.3	12.5
21	1-18-inch	10/25	11.8	12.7	11.8	11.4	11.9	10/25	11.8	12.1	12.4	12.0	12.1	12.0
22	1-18-inch	10/29	12.2	13.6	13.4	12.7	13.0	10/29	11.3	10.3	10.1	10.4	10.7	11.8

* Corrected to average basis

The draft ratings given in Table 2 then represent the comparative power requirements of the 21 plows for which satisfactory draft records were obtained on Field No.1 and form the basis for a study of the effect of packing by tractor wheels upon soil resistance, and of weight of plow, type of rear support, and shape and size of plow bottom upon the power requirements of the various plows. The method of graphic correlation described by Bean (3) was followed in making this analysis.

Soil and weather conditions.

The soil of Field No.1, which lies about 4 miles west of Dundee, Michigan, is a dark clay loam, well underdrained, and fairly well supplied with organic matter through use of sweet clover in the rotation and return of crop residues to the soil. The field is almost level and appears very uniform, though as the work progressed local differences in character of the soil were noted. Plow tests were commenced in this field on October 12, 1928, but at that time the soil was so dry and hard that satisfactory coverage of stalks was impossible and draft was very high, plow No. 19 requiring 15 pounds pull per square inch of furrow cross-section. Work was stopped until rains, commencing on October 15, softened the soil. The distribution of this rainfall, (Figure 5), was taken from Government records at Toledo, Ohio, about 30 miles southeast of the field, and checked with the record of the Corn Borer Laboratory at Monroe, Michigan, about 20 miles east. During the two weeks required to complete the tests weather conditions fluctuated less than is usual at this season of the year.

Table 2.- Description of plows used in draft tests on field No.1

Plow No.	Size	Draft Rating	Width Packed by Tractor Wheels	Weight per Sq. In. Furrow Slice	Type of Rear Support 1/	Depth at Mid-section Ratio	Angle of 3 Inch Contour
		Per cent	Per cent	Pounds			Degrees
1	2 12-inch	106	48	3.6	A	1.03	27
2	2 12-inch	105	48	3.4	A	1.00	43
3	2 14-inch	107	41	4.5	B	.87	38
4	2 14-inch	107	41	4.9	B	.97	40.5
5	2 14-inch	101	41	4.4	C	.97	40
6	2 14-inch	99	41	3.1	A	.97	28
8	2 14-inch	91	41	4.3	C	1.11	42
9	2 14-inch	100	41	3.1	A	1.11	42
10	2 14-inch	102	41	5.0	B	.99	37.5
13	2 16-inch	96	36	4.0	C	.94	36.5
14	2 16-inch	108	36	4.4	B	.88	40
15	2 16-inch	95	36	4.0	C	1.03	34
16	2 16-inch	97	36	4.4	C	1.03	42
17	2 16-inch	99	36	3.9	C	.95	39
18	2 16-inch	91	36	2.8	C	.99	41
19	2 16-inch	97	36	4.1	B	1.18	32.5
23	2 18-inch	96	32	3.7	C	.94	40
24	2 18-inch	100	32	4.8	C	.93	40
12	1 16-inch	113	72	4.3	A	1.05	35
20	1 18-inch	114	64	5.0	C	.96	41
22	1 18-inch	121	64	4.1	A	.93	40

1/ A - No Rear Wheel
B - Rear Wheel--Incomplete Support
C - Rear Wheel--Full Support

Data presented in Table 3 suggest that plows Nos. 2, 9, 16, 19, 23, and 24 are about average plows, as far as draft is concerned; that plows Nos. 3, 4, and 14 require more than average power; and that plows Nos. 8, and 15 require less than average power.

EFFECT OF RAINFALL ON SOIL RESISTANCE

In Figure 5 the average drafts per square inch (Table 1) are plotted according to the dates on which the tests were made. At the top of the sheet is plotted the cumulative rainfall. It will be seen that a close relationship exists between soil moisture and draft, for on October 15, when the ground was very dry, the draft of plow No.19 was 15 pounds per square inch, while on November 1 the draft of the same plow was only 10.5 pounds per square inch. The grouping of the points suggests, however, especially if the single bottom plows, represented by circles, are disregarded, that the soil resistance was at its minimum on October 25 and 26, immediately after the rains, then gradually increased as the moisture evaporated or soaked into the subsoil until further rains occurred on November 2. The dotted line indicates the probable changes in soil resistance in this field during the test period.

Rainfall of 1.3 inches between October 15 and 22 increased the moisture content of the top 8 inches of soil by not more than 10%, moistening rather than wetting it, yet this change reduced the soil resistance by about 40%. This indicates the great importance of plowing when soil conditions are right, while the rapid rise of the curve after the rain suggests how quickly conditions may become unfavorable.

Table 3.- Comparative draft of plows run side by side and average draft per square inch

Plow No.	Sandy Loam	Sandy Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam
	Ratio	Ratio	Ratio	Ratio	Ratio	Ratio
2	99	--	--	--	--	--
3	--	--	--	120	--	--
4	--	108	--	--	--	--
8	--	100	--	--	--	89
9	95	--	--	--	--	111
14	108	--	--	--	--	--
15	--	--	--	84	--	--
16	--	--	--	96	--	--
19	--	98	--	--	--	--
23	--	--	99	--	103	--
24	97	95	101	--	97	--
Ave. Draft in lbs. per sq.in.	5.04	6.53	7.41	8.04	8.77	7.97

Type of Soil

Note: Depths of plowing were between 6 inches and 8 inches. Plows in each field were run at approximately equal depth.

The discussion of soil characteristics by Nichols (9) is interesting in this connection, though no estimates of effects of soil changes on draft are included. It appears from the data presented that reduction in draft within the moisture range represented by these tests--probably 15% to 25%--takes place as the result of the loosening of the moisture films rather than from changes in friction. Some data on the compressive strength of Gila clay loam, presented by Botkin (4) shows an interesting comparison with the present case. His data show that as the moisture in the specimens tested increased from about 10% to about 19% the compressive strength dropped from 100% to about 65%.

EFFECT OF PACKING ON SOIL RESISTANCE

Packing by tillage machinery.

Comparative tests of covering power and draft were made in several fields where part of the land had been disked, part double disked, and part rolled with the cultipacker to flatten the stalks before plowing. The implements were tractor-drawn in all cases. Table 4 presents some results of these tests, expressed in percentages of the draft on the untreated portions of the same fields.

Variations in soil type doubtless account for part of the irregularities in the data, but it seems clear that working clay loam soils with tractor-drawn implements, when damp or moist, causes a net increase in draft, though this did not appear to be the case in the field that was worked when dry. It seems likely that this increase is caused largely by the tractor.

Table 4.- Comparative effect on draft of plows of tillage treatments on clay loam soil before plowing

Field	Condition when treated	None	Single disked	Double disked	Rolled
		Per cent	Per cent	Per cent	Per cent
A 1/	Damp	100	113	126	--
No.1 2/ 6-in.Depth	Moist	100	99	107	100
No.1 8-in.Depth	do	100	107	118	111
No.1, Ave.	---	100	103	112.5	105.5
No.3 6-in.Depth	Dry	100	105	99	99

1/ A single-bottom 16-inch plow used in Field A.
2/ Averages for Field 1 include 17 two-bottom, and for Field No.3 include 6 two-bottom plows.

Packing by tractor wheel when plowing.

A short series of tests was made on moist clay loam soil in the spring of 1928 to determine the relative draft of 1, 2, and 3 bottom plows. A convertible plow using 1, 2, or 3 bottoms was operated at about 7 inches depth and speed of $2\frac{1}{2}$ miles per hour, using a light 15 - 27 tractor with spade lugs. Draft was recorded by the Iowa dynamometer. The draft and weight of the plow and the percentage of plow width packed by the tractor wheel under the three set-ups are given in Table 5.

Three variables, namely; weight of plow, amount of side draft, and percentage of packed earth evidently are involved in the greater draft of the single bottom plow, though part of the side draft was carried by the tractor. After making allowance for side draft and

Table 5.- Comparative data for a convertible one to three bottom plow

Number and size of bottoms	Weight per sq. inch of furrow slice	Plowed land packed by tractor wheel	Draft per sq. inch of furrow slice	Relative draft
	Pounds	Per cent	Pounds	Per cent
1 - 16-inch	6.25	72	8.77	120
2 - 16-inch	4.20	36	7.32	100
3 - 16-inch	3.50	24	6.10	83

weight of plow it seems probable that at least half of the differences in draft are due to packing of the soil by the tractor.

The effect of packing by the tractor while plowing was also studied for Field No.1. The draft of the plows shown in Figure 5 is expressed in percentages of the soil resistance in Table 2. It will be noted that variations from the average of the double plows run from 91% to 107%, while the drafts of the three single bottom plows are from 113% to 121% of the average, showing some marked difference between the double and single types. Weight, side draft, and percentage of ground packed by tractor wheels seem to be responsible for this, the latter factor probably being most important.[3] Therefore, in Figure 6, the draft expressed in percentages is plotted against percent of ground packed by the left tractor wheel. The graph indicates clearly that packing by the tractor increased the draft.

3/ Except when they run in the tractor track, the percentage of power used by colter and jointer is approximately the same whether a plow has one or three bottoms. This is true of the convertible plow discussed above , and in cases where single and double plows use bottoms of the same size. It is this group of plows that best shows the variations in draft due to packing of the soil.

Location of line in Figure 6 showing influence of packing.

Study of Table 2 shows that a wide plow not only has a comparatively small per cent of its furrow packed by the tractor wheel but usually weighs less per square inch of furrow slice than a narrow one. In addition, plows 12 and 22, 4/ represented by extreme points in the scatter diagram, may be expected to require more than normal draft since they do not have rear wheels. Therefore, the line representing influence of packing on draft must be located to make allowance for the influence of these two other factors. The dash line marked "first approximation" was drawn with these points in mind, passing approximately through the center of the group of points, and having a slope slightly greater than the line based on packing by tillage implements before plowing. The "second approximation" was arrived at after a consideration of the effects of weight, type of rear support, etc., as discussed in later paragraphs, and takes almost exactly the slope of the line for packing by tillage implements. For a full description of this method of graphical analysis see (3).

EFFECT OF PLOW CHARACTERISTICS ON DRAFT IN FIELD NO.1

Weight of plow.

The weight of each plow was expressed in pounds per square inch of furrow slice by dividing total weight by its average cross sectional area of furrow slice. Figure 7 shows that an increase in weight of plow from 3.0 pounds per square inch of furrow slice to 5.0 pounds per square inch increased the draft by 3½%; or, based on the average draft in this field, the draft due to weight alone increased at the rate of .185 pound per pound of

4/ To correct for the effect of side draft on the single bottom plows, only two-thirds the variations from normal were plotted for plows 12, 20, and 22.

total weight, which is relatively small. Draft due to weight of a single bottom 16-inch plow weighing about 700 pounds would then be about 130 pounds which compares with 100 pounds reported by Collins (5) for a similar plow running light. This seems reasonable, for the distribution of the load between rolling and sliding friction may very likely change when the plow is at work.

Type of rear support.

Classification of plows with rear wheels as between full support and incomplete support is a little unsatisfactory since soil conditions, hitch adjustment and set of rear wheel all affect the bearing. Even those plows listed as having full support did not carry all the weight on the wheels all the time. Figure 8 indicates that a rear wheel giving full support reduces the draft about 7% as compared with a similar plow having no rear wheel.

Plow bottom shape.

The arrangement of the points about the second approximation line in Figure 8 shows deviations from 9% plus to 10% minus. It may be assumed that these deviations represent the variations in draft due to plow bottom shapes, after the effects of soil resistance, packing, weight, and type of rear support have been eliminated, and include whatever accidental errors may have occurred during operation. While the majority of the deviations are unimportant and bear out the statement by Collins (5), that "The type of bottom does not materially influence the draft," nevertheless the maximum deviations are large enough to justify a study of these factors.

Since it is generally accepted that a major part of the work of a plow is done by the share, the shares of all plows tested were examined with

respect to shape. All shares were new and in good condition, and the shapes of the points were very much the same. No general tendencies in shape of points were found to satisfactorily explain variations in the draft.

The horizontal angle made by the cutting edge of the share with the direction of motion varied from 37 degrees to 46 degrees and the angle to the direction of motion made by the contour line drawn 3 inches above the plow sole varied from 27 degrees to 43 degrees. A slight decrease in draft was noted in connection with the smaller angles on the 3-inch contour line, but neither set of angles seemed to have an important influence on draft.

A study was made of the relation between draft and the shape factors described in "A Method of Comparing Plow Bottom Shapes" (2). As shown in Figure 9, there appeared to be a well marked relationship between draft and the slope of moldboard at the mid-section, those plows having the steeper slope, in proportion to their size, showing the heavier drafts. There was no conclusive evidence as to other factors that influence draft.

Size of plow bottom.

The analysis does not show that size of plow bottom has much effect on draft. However, the data are complicated by the use of colters and jointers on the plows since one colter and jointer of each 12-inch and 16-inch plow ran squarely in the path of the tractor wheel; one colter and jointer of each 14-inch plow ran just at the inner edge of the wheel track; while neither colter nor jointer of the 18-inch plows followed the wheel track. Soil resistance in the wheel track appears from Figure 2 to have been about 25% higher than that of unpacked earth.

EFFECT OF DEPTH OF PLOWING ON DRAFT

Seventeen of the two-bottom plows tested in Field No.1 were run at both 6-inch and 8-inch depth on each of the four soil treatments, as shown in Table 1. The soil had been worked to 8-inch depth for several years and was fairly uniform throughout the furrow slice. The ratios of draft per inch width of cut at 8-inch depth to those at 6-inch depth, grouped according to size of plow are shown in Table 6. To find if there was a general change in the level of soil resistance at the two ends of the field, the draft near the dividing line between the two depths was read from the records so that in most cases corresponding readings were obtained for points only about 100 feet apart. The results indicate that soil resistance was slightly higher at the end of the field where the 6-inch tests were made.

Table 6.- Ratios of draft per inch width of cut at 8-inch depth to draft under similar conditions at 6-inch depth

Number of plows in group	Size of plows	Soil treatments before plowing: None	Single disked	Double	Rolled with cultipacker	Average	Average of records of center line
1	12-inch	1.05	.97	1.14	1.14	1.07	1.10
7	14-inch	1.09	1.22	1.21	1.19	1.18	1.20
7	16-inch	1.04	1.13	1.16	1.18	1.13	1.17
2	18-inch	1.01	1.03	1.04	1.18	1.07	1.09

Table 6 indicates that 18-inch plows are slightly more efficient for deep plowing than 16-inch or 14-inch plows. It is unfortunate that only one 12-inch plow was tested, since soil variations probably account for the small increase in draft at 8-inch depth.

The data also indicate that under uniform soil conditions an increase

of 33% in depth (from 6 inches to 8 inches) resulted in an increase in draft of only 14% or 16%. This seems in accord with the results of Collins' experiments (5) showing that about 50% of the draft is expended in cutting loose the furrow slice, 20% in moving the plow, and only 30% in turning the furrow. If the plows had run below the old plow sole, it is probable that the draft at 8 inches depth would have been much greater on account of the greater stiffness of the subsoil. Data obtained in other fields were so inconsistent, apparently from this cause, that they are not presented here.

EFFECT OF SPEED ON DRAFT

A series of tests was made in the fall of 1928 to find the comparative draft at $2\frac{1}{2}$ and $3\frac{1}{4}$ miles per hour, other conditions being the same at both speeds. The soil was similar to that in Field No.1. Each plow crossed plots of standing, single disked, double disked, and rolled stalks at low speed, and a similar set of plots at the other end of the field at high speed. Soil and weather variations affected the results, and there were variations in speed, since there was some tendency, especially with the larger plows, for the tractor to slow up a little in hard ground. The data are shown in Table 7.

The average draft of the whole group shows an increase of 8.6% at the higher speed, and the average of the 14-inch group shows a 10.6% increase.

Greater ranges of speed were possible in the tests run during the summer of 1931, in the field described on p. 5 . Since it was not possible to hold moisture conditions constant each of the series shown in Table 8 was run in from one to two days, thus giving very little time for moisture changes, but more time necessarily elapsed between the series, thus accounting for the moisture variation. The draft increased as the per cent of

Table 7.- Relative draft of plows at speeds of $2\frac{1}{2}$ and $3\frac{1}{4}$ miles per hour in Field No.2 at 6-inch depth

Plow No.	Size	Draft at $2\frac{1}{2}$ m.p.h.	Draft at $3\frac{1}{4}$ m.p.h.
		Pounds per sq. in.	Pounds per sq. in.
3	2-14	9.69	10.14
8	2-14	6.98	8.27
9	2-14	8.97	10.00
26	2-14	9.78	11.32
27	2-14	9.55	10.00
13	2-16	7.45	8.91
15	2-16	6.76	7.20
16	2-16	7.68	7.57
23	2-18	9.71	9.79
Average of all		8.51	9.24

Table 8.- Summary of data obtained from tests made in Field No.9

Series No.	Bottom No.	Number of tests	Average depth	Speed range in	Power source	Moisture content of soil	Equation of curve 1/
			Inches	Mi.per hr.		Per cent	
1	19	23	7.1	2.5 to 6.2	Cable	25.5	$y = 3.53 - 1.036x$
2	19	21	7.2	1.8 to 4.1	Fordson	25.5	$y = 3.52 - 1.173x$
3	19	27	6.6	1.3 to 6.8	Cable	23.0	$y = 3.86 - 1.212x$
4	19	27	6.9	.9 to 4.4	Fordson	23.0	$y = 5.43 - .675x$
5	57	27	6.9	1.0 to 6.0	Cable	20.4	$y = 6.46 - 1.265x$
6	57	27	7.2	1.0 to 4.4	Fordson	20.4	$y = 5.98 - 1.303x$

1/ In these equations: y = Draft per square inch of furrow slice cross section expressed in pounds and x = Speed in miles per hour.

moisture in the soil decreased. When the moisture content dropped to 20.4%, the increased draft caused excessive slippage of the left tractor wheel. This loosened the top soil and probably was the reason for the draft being lower in series 6 than in the cable tests (series 5) which were run concurrently. Series of tests were run concurrently using a standard light tractor and a cable draft arrangement. (Figs. 3 and 4) Figure 10 is a scatter diagram for one series of tests. A study of this diagram indicates that the data for this particular series might better be fitted by a parabolic form of curve, but since the data for the other five series do not show this tendency a straight line of best fit, as determined by the method of least squares, is used. The curves determined by the data for the six series of draft tests are shown in Figure 11.

A study of these curves and Table 8 indicates that the average increase in draft with the two bottoms used was 1.17 pounds per square inch of furrow slice for each mile per hour increase in speed. This is a higher rate of increase than was found by Collins (5); perhaps on account of differences in soil. The bottoms were of types in common use. It seems probable that bottoms designed for high speeds would not show such a high rate of increase in draft.

EFFECT OF PLOW ATTACHMENTS ON DRAFT

Three short series of tests were made in the spring of 1928 to find the effect of plow attachments upon draft, with the results shown in Table 9. Eighteen-inch colters were used on the 18-inch plows and 16-inch on the 16-inch plow. Jointers were of medium size of the type furnished for corn borer plows, and cleared a strip averaging about 4 inches wide next to the colters. Two wires were used.

Table. 9.- Effect of plow attachments on draft

Type of soil	Depth of plowing	Size of plow	Colter jointer & wires	Colter and jointers	Colter and wires	Colter only	Jointer and wires	Jointer only
	Inches		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Sandy loam	7 - 8	18-inch	100	98	90	88	98	87
Clay loam	6 - 7	18-inch	100	--	93	95	--	--
Clay loam	6 - 8	16-inch	100	--	95	90	--	--
Average	7		100	98	93	91	98	87

From these data it appears that two 10-foot covering wires increase the draft about 2%. Other tests indicate that three wires pull very little harder than two since they usually wrap together and pull through the soil as a unit. It appears that the ordinary jointer used for corn borer control absorbs about 7% of the power when used with the coulter, and that the use of jointer alone requires less power than colter and jointer together. It seems probable that colter, jointer, and wires together absorb between 10% and 15% of the total power. In view of their value in covering trash this is power well spent.

CONCLUSIONS

For economy of power, plowing should be done during relatively short periods when moisture conditions are best. Plowing done at these times also produces the best seed bed with least work and covers trash most completely.

Packing of moist clay loam by tillage machinery definitely increases power requirements for plowing. This increase in soil resistance suggests injury in other respects, and emphasizes the importance of minimum weight and suitable wheel equipment for all tillage machinery.

The draft of plows designed for ordinary speeds increases rapidly with increases in speed.

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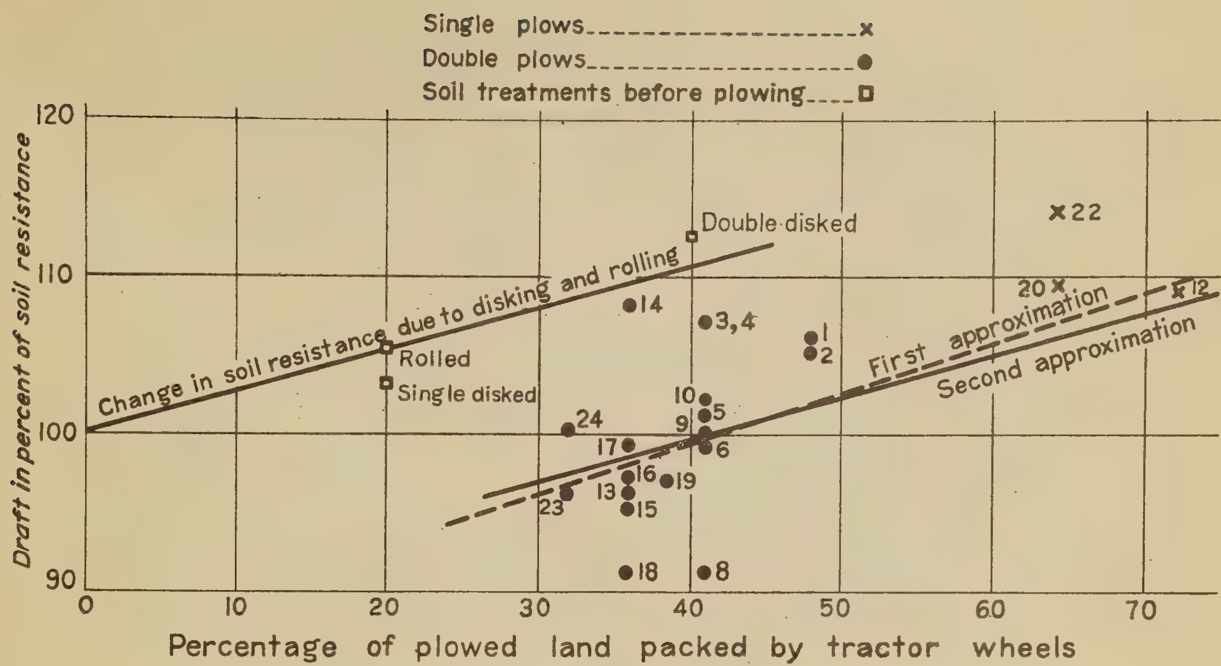

Fig. 6 – Apparent effect of packing by tractor wheels on draft

The deviations from the first approximation line in Figure 6 are plotted against the weight of the plow in pounds per square inch of furrow slice, and an approximate line fitted to the points, passing as nearly as possible through the center of the group

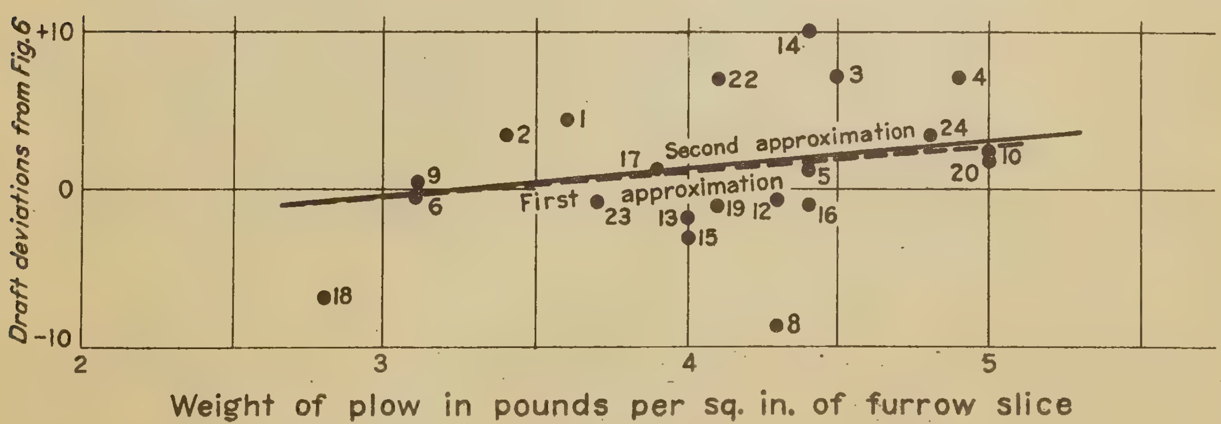

Fig. 7 – Effect of weight of plow on draft

The deviations from the first approximation line in Figure 7 are plotted against type of rear support. The first approximation line was fitted as before; points representing plows 22, 23 and 24 having similar bottoms, were used as guides for the slope and the second approximation line was fitted as shown

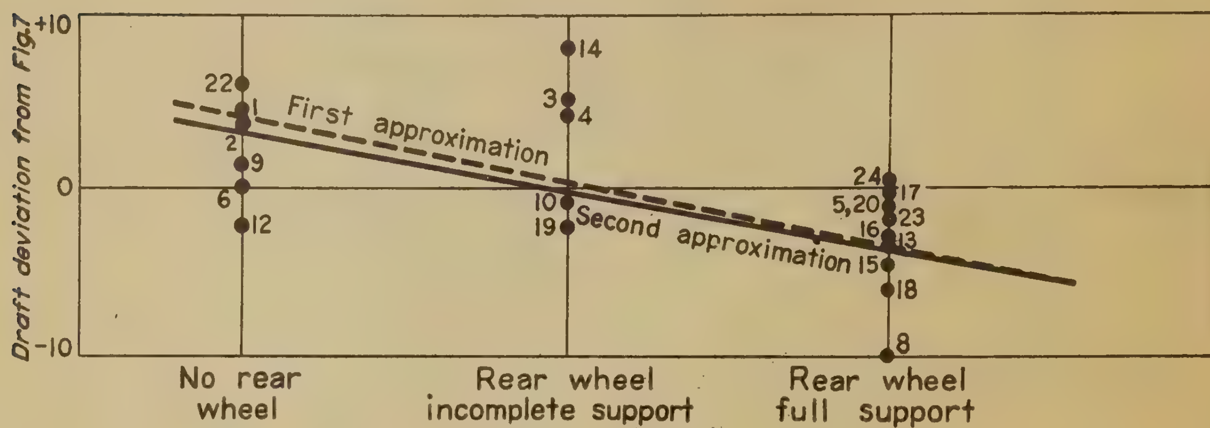

Fig. 8 - Effect of type of rear support on draft

The deviations from the first approximation line in Figure 8 are plotted against the ratios of actual to normal for plows of the same sizes and of good covering ability

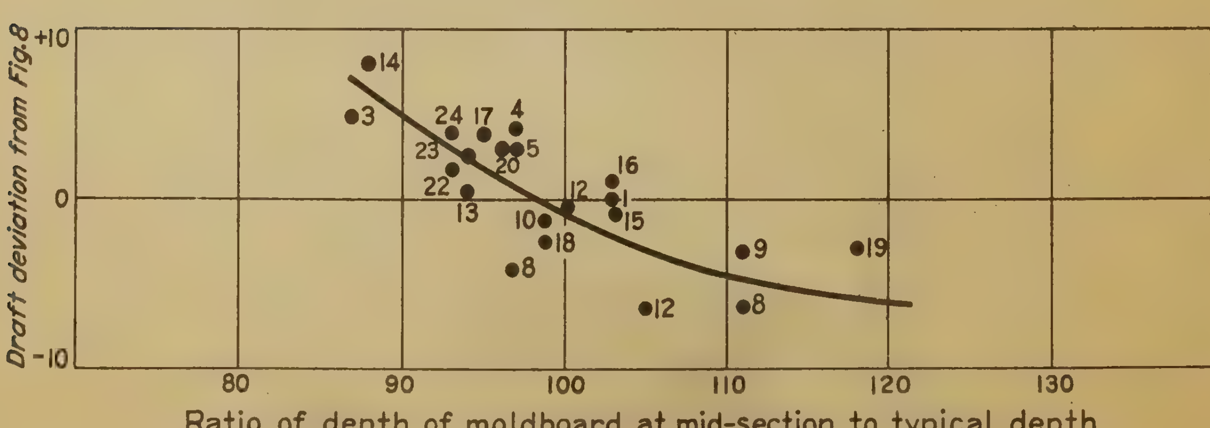

Fig. 9 - Effect of slope of moldboard at mid-section on draft

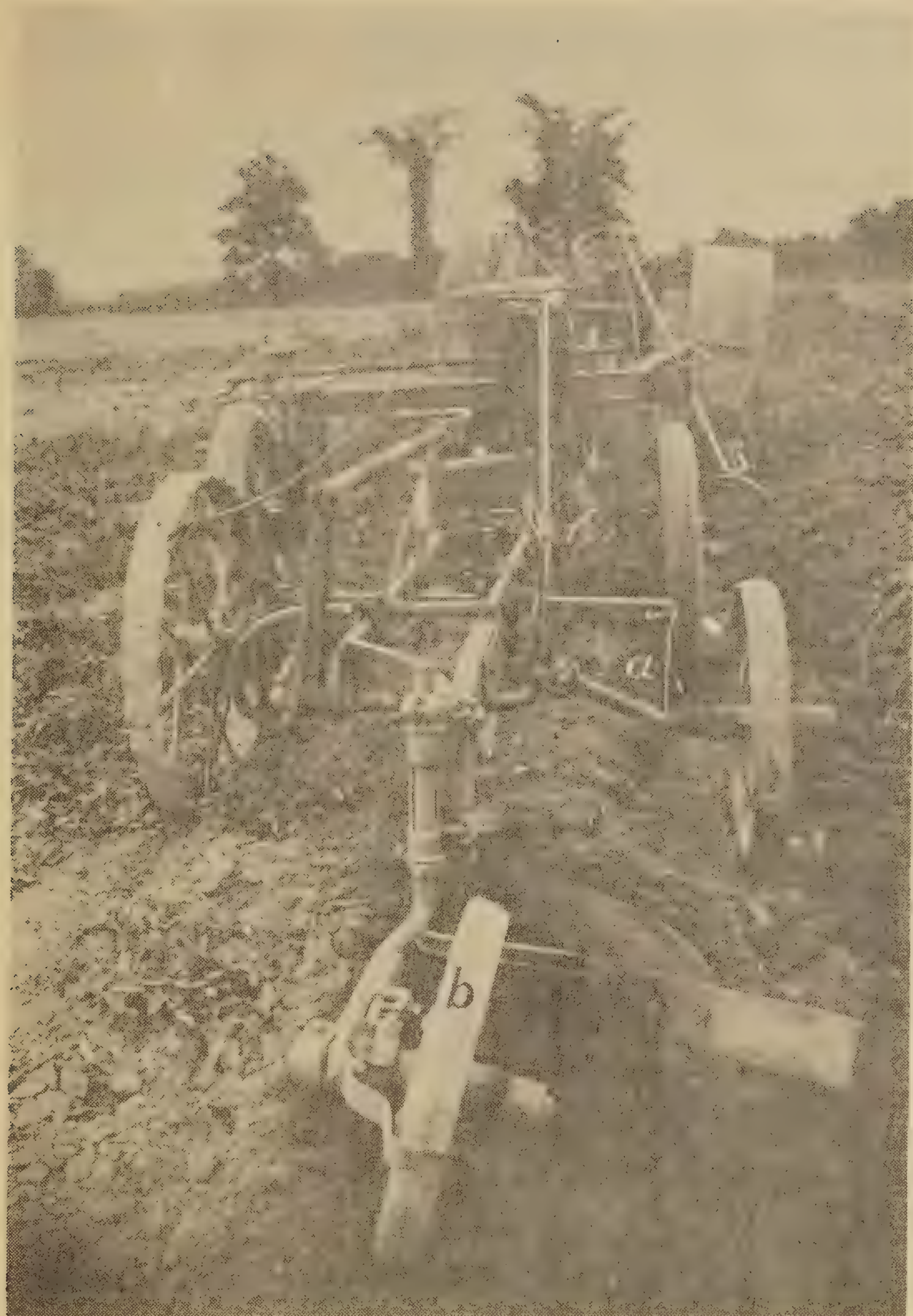

Figure 4.- View of test frame and dynamometer cart showing alignment of equipment for operation. Notice width gage (a) on plow and fully adjustable rear wheel (b) arrangement that can be set to hold any standard plow bottom in its proper position.

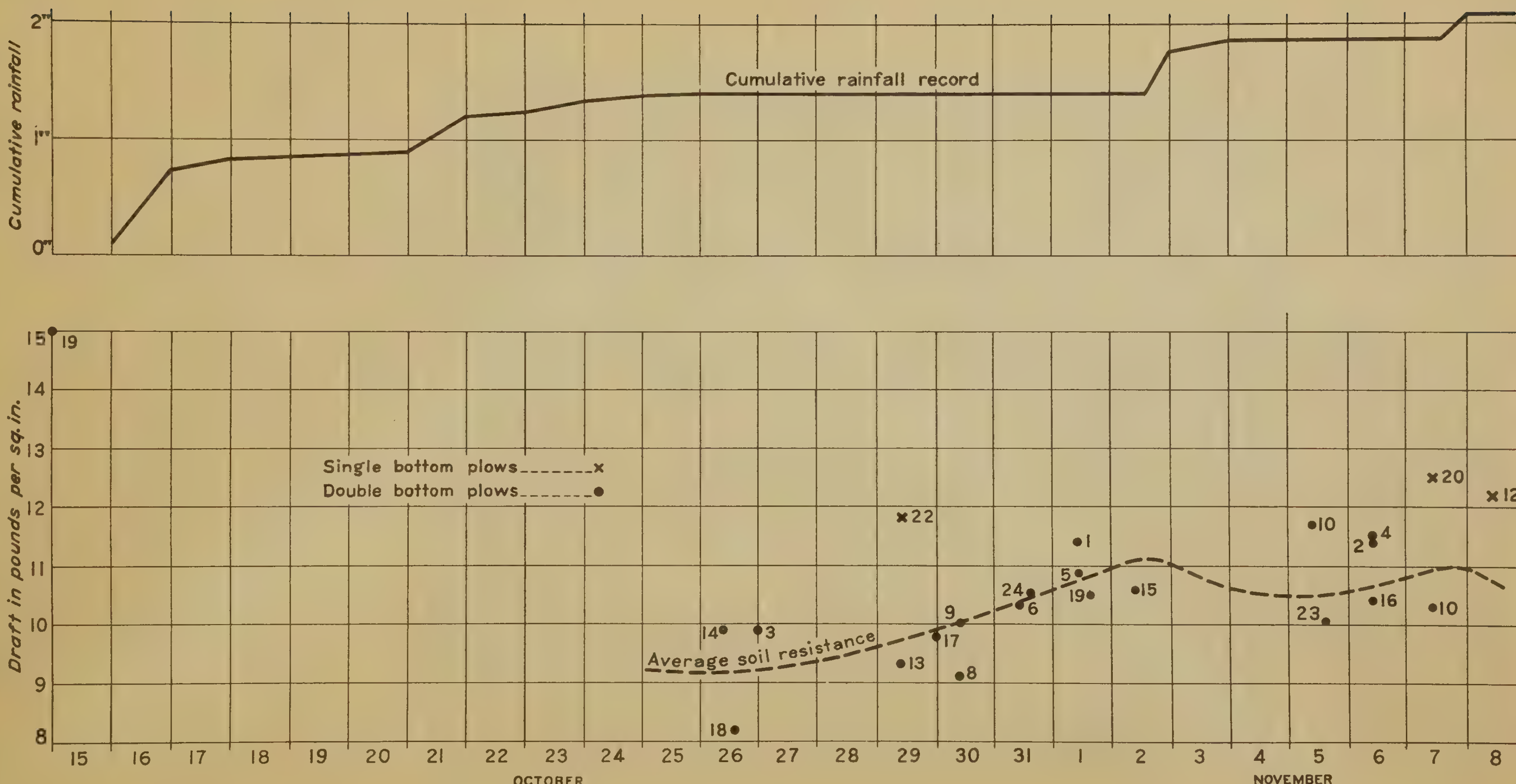

Fig. 5 - Relation of soil moisture to draft of plows

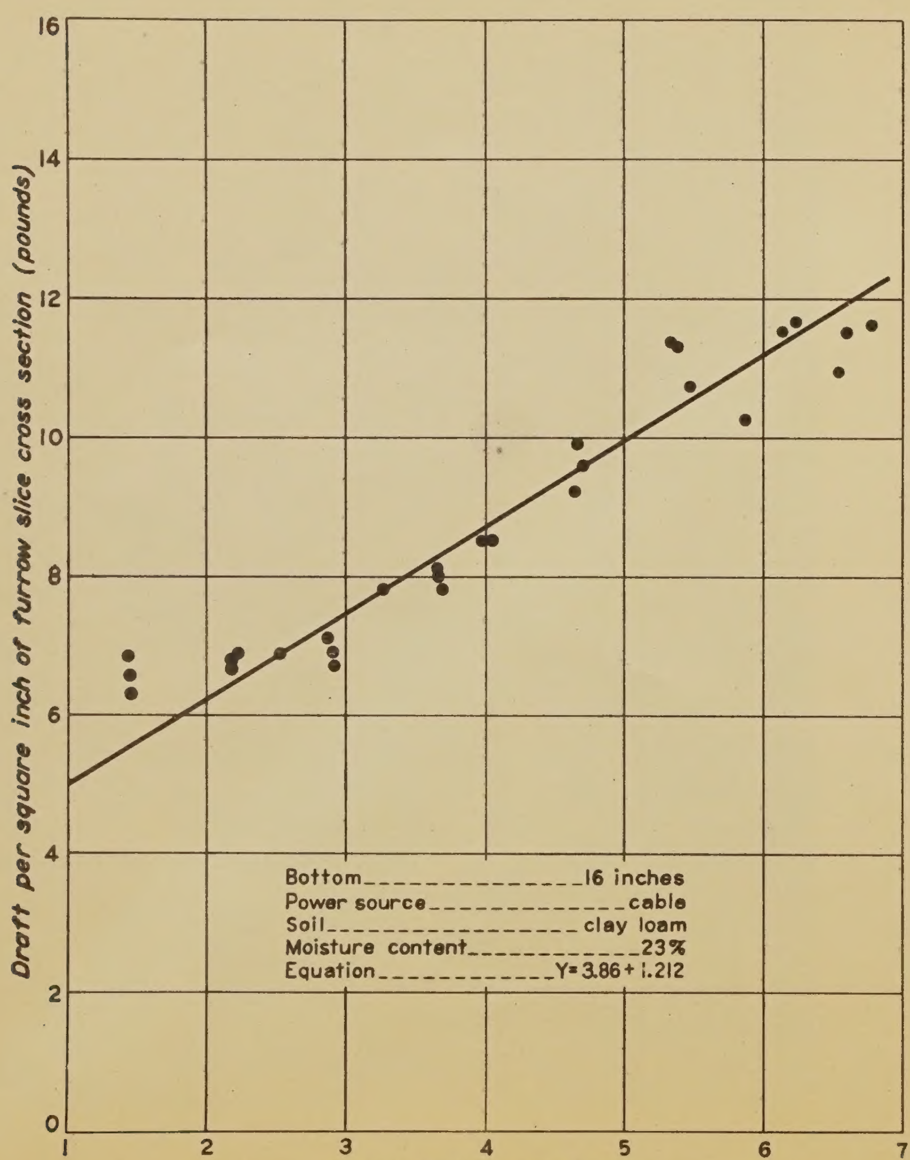

Fig.10 – Draft tests showing effect of speed

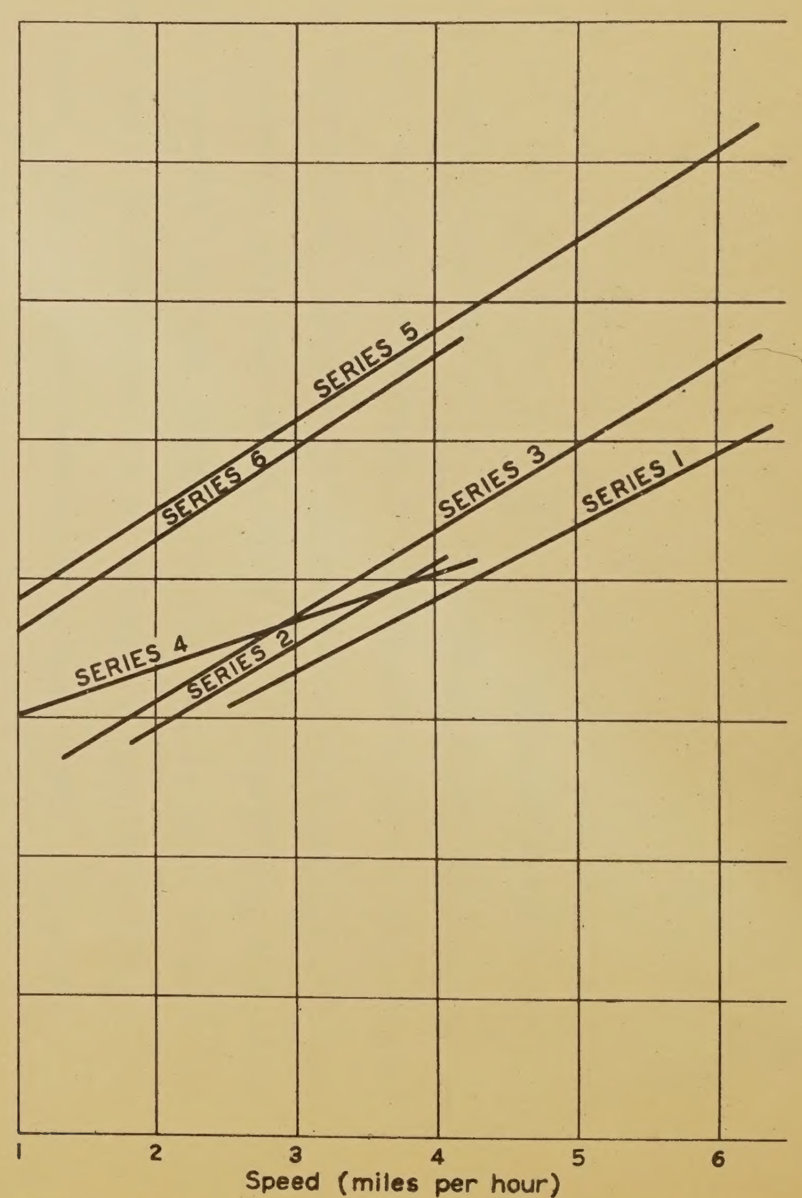

Fig.11 – Curves determined by method of least squares

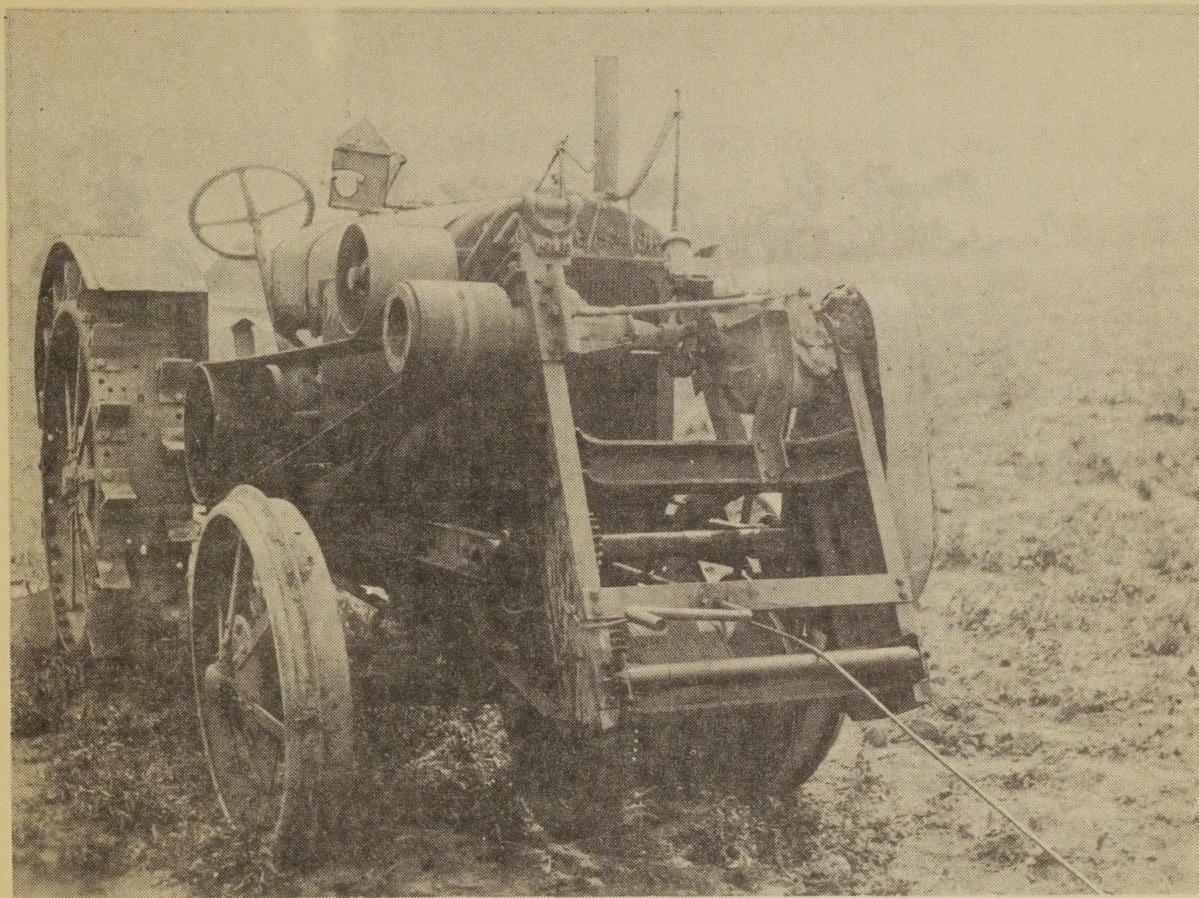

Figure 3.- Cable tractor arrangement used for draft tests. It consists of a 30 H. P. tractor with a hoist mounted in the front and arranged to drive from the belt pulley through a standard three speed auto transmission. The motor is equipped with a specially designed throttle adjusting governor arrangement. By adjusting the governor for varying motor speed and by using the different speeds in the transmission it is possible to obtain any cable speed between .9 and 6.8 miles per hour.

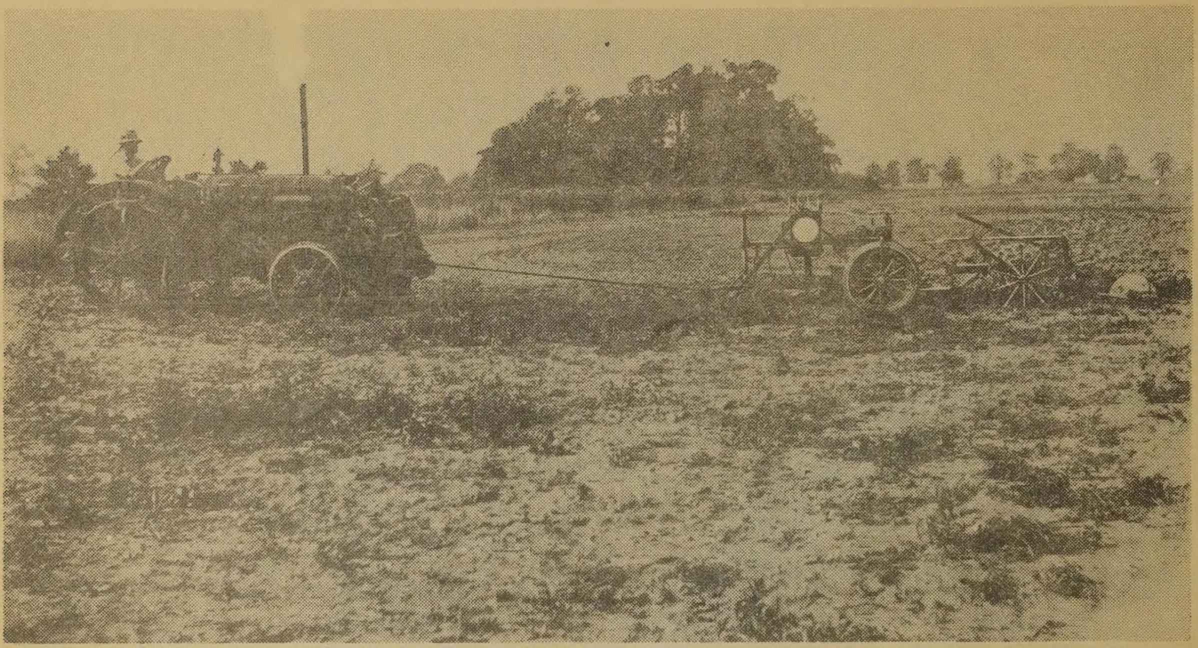

Figure 1.- Cable tractor and dynamometer cart as arranged for draft tests. The dynamometer cart carries the plow hitch at the proper height and keeps the plow cutting uniformly at its normal width.

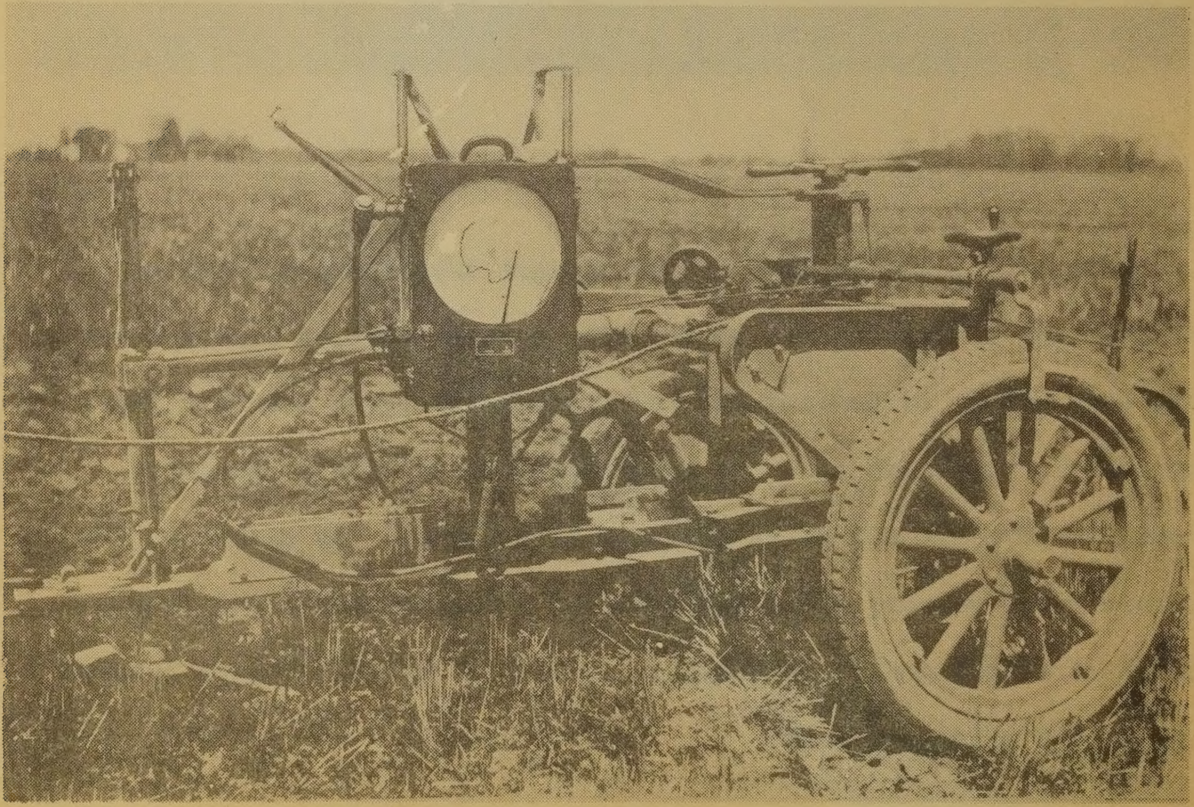

Figure 2.- Dynamometer cart designed to carry dynamometer and front end of plow when using the cable tractor. All adjustments are made by crank or similar device over a graduated scale. Adjustments of drawbar on cart are recorded and thus it is always possible to duplicate any adjustment.